Machine Learning in Robotics

Does machine learning need robotics?
Does robotics need machine learning?

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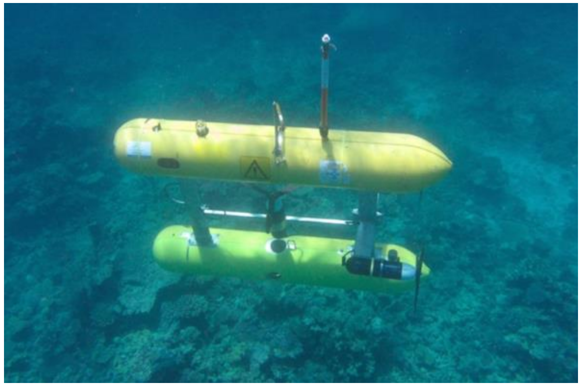
- Related Courses
  - Artificial intelligence in summer semesters
  - Deep learning in winter semesters
  - Robotics II in summer semesters

- What to expect?
  - Applications
  - Challenges
  - Potentials of machine learning in robotics



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- Genesis of Intelligent Robots
  - Mass production and precision → Manipulator robots



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  - Handling of dangerous material → Teleoperation

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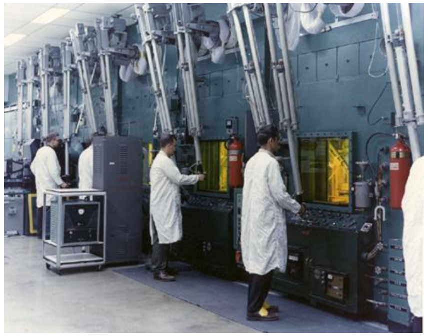
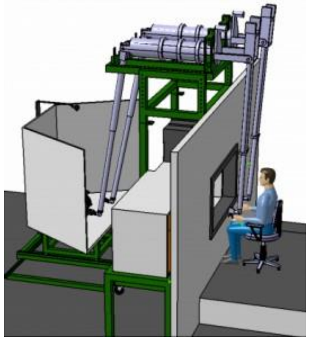
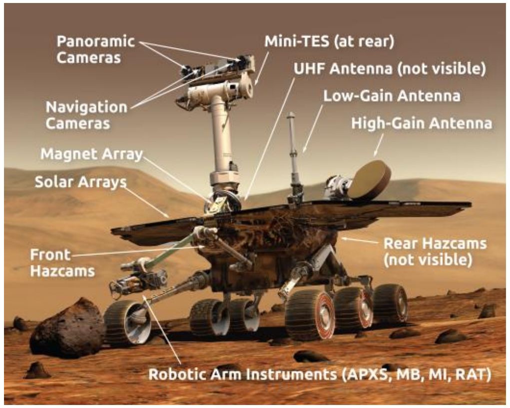



- Genesis of Intelligent Robots …Cont’d
  - Space exploration → Telecontrol → Intelligent robots



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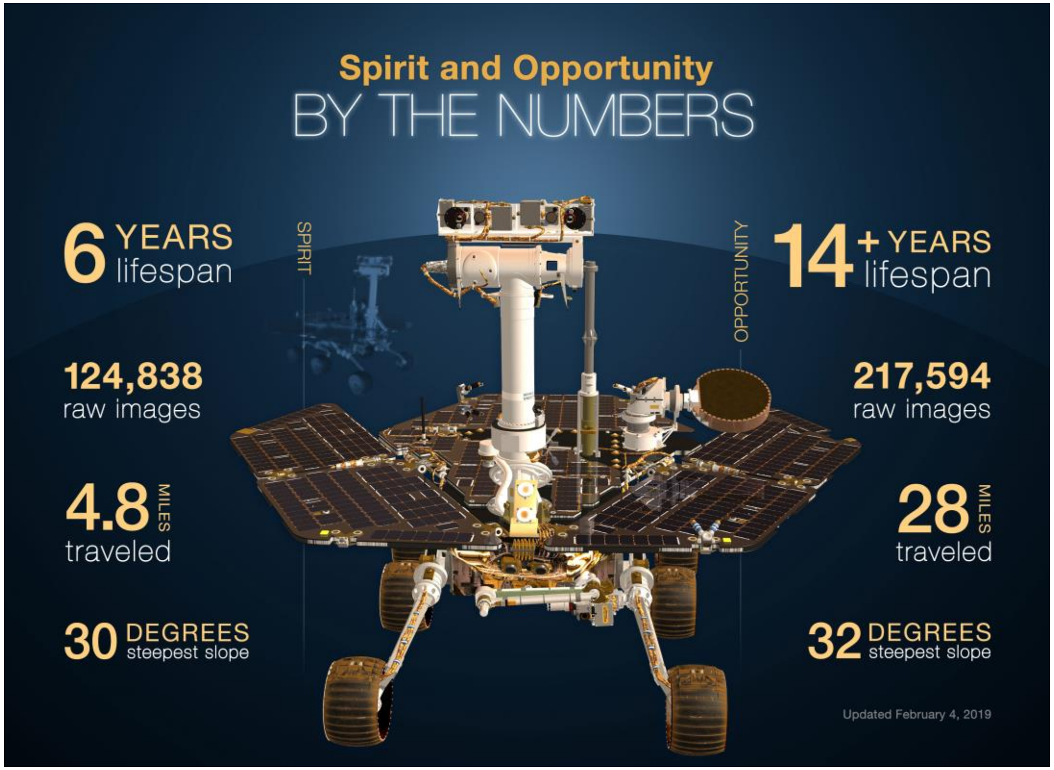
- Genesis of Intelligent Robots …Cont’d
  – Space exploration → Telecontrol → Intelligent robots



Distance to Mars :
- 56M – 400M km

Signal travel time (one way) :
- 3 – 22 minutes

Spirit travelled :
- 0.8 miles/year
- 1.3 km/year

Opportunity travelled :
- 2 miles/year
- 3.2 km/year

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- Genesis of Intelligent Robots …Cont’d
  - Further motivation for intelligent robots
    - Human machine interaction
    - Flexible manufacturing
    - Complex environments and tasks (uncertainty)
    - Intelligent environments
      - Intelligent homes, Intelligent industries, etc.
    - Control of complex agile mechanical systems

- Terminology
  - What is AI?
  - What is machine learning?
  - What is deep learning?
  - What are robots?
  - What is robotics?

• Terminology …Cont'd

• What is AI?

Thought process and reasoning	**Thinking Humanly** "The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985) "[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978)	**Thinking Rationally** "The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985) "The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992)
Behaviour	**Acting Humanly** "The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990) "The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)	**Acting Rationally** "Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998) "AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998)
	Reference to human	Rationality

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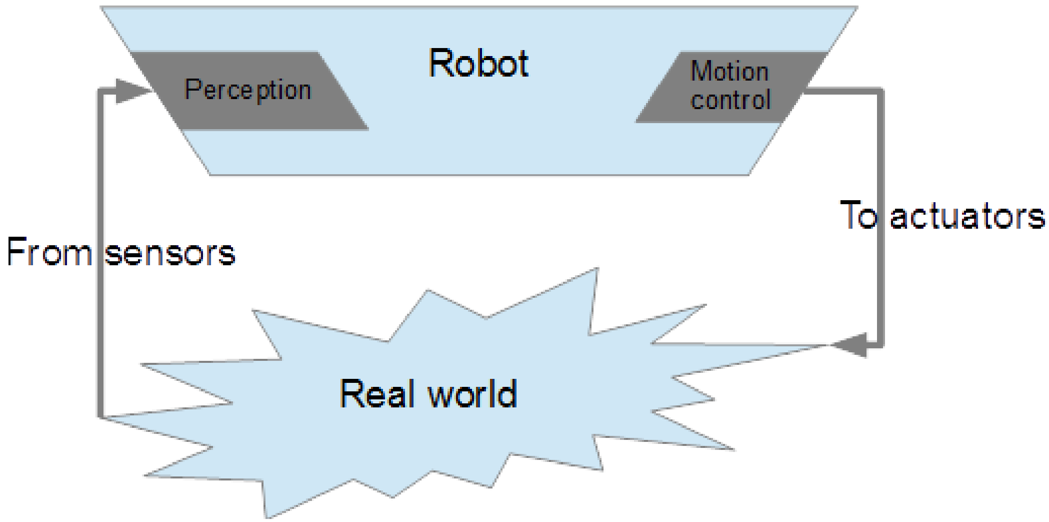
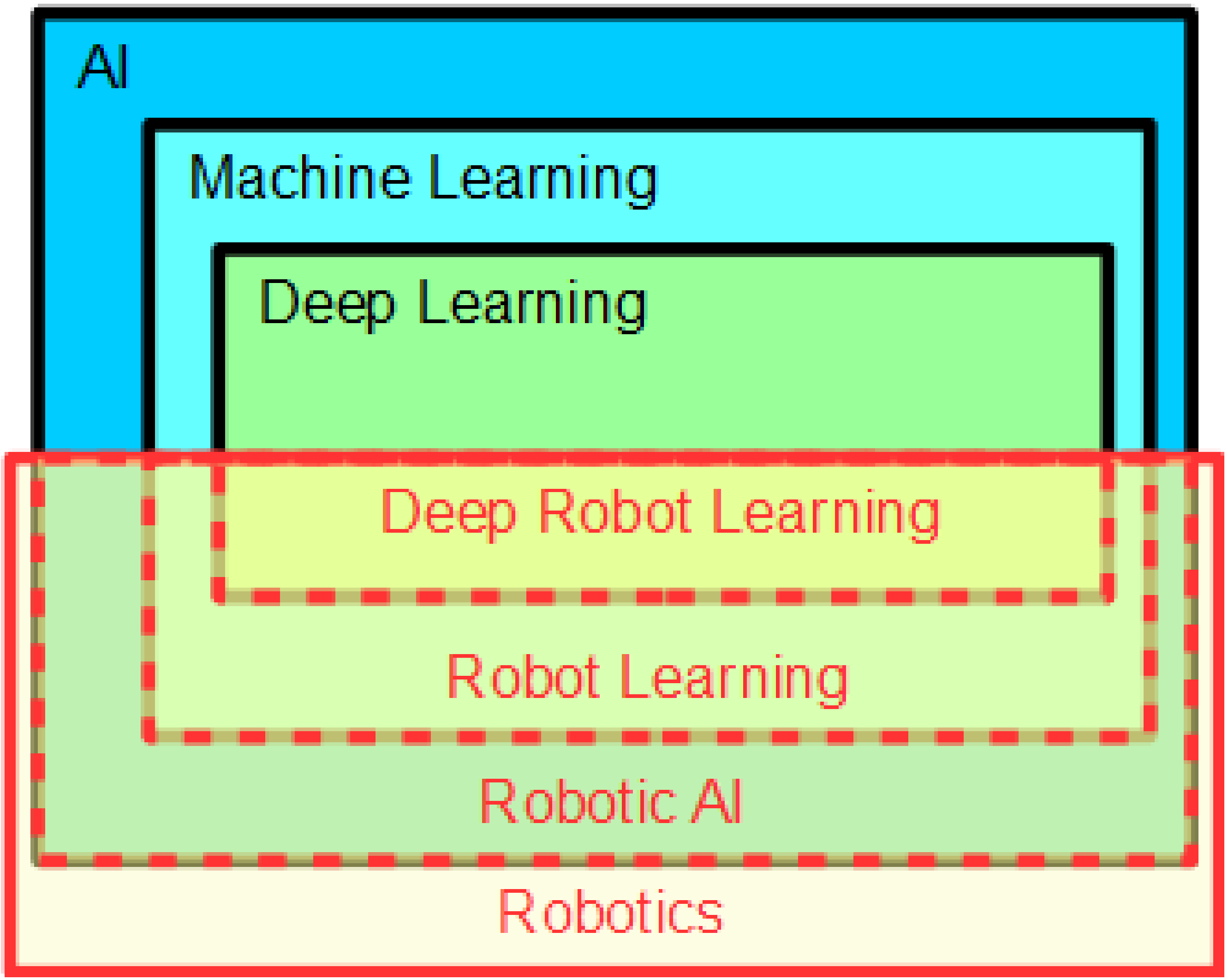
- **Classes if AI: Applied AI, Generalized AI and Super AI**

- Terminology …Cont’d
  - What is machine learning?
    - Ability of a system to acquire their own knowledge, by extracting patterns from raw data [9]
  - What is deep learning?
    - Is a function approximation method [9]
    - It builds a hierarchical representation graph where simpler concepts are assembled into complex concepts

- Terminology …Cont'd
  - What are robots?
    - Mechanical systems equipped with one or several effectors capable of manipulating the physical world
  - What is robotics?
    - The study of intelligent mapping from robot perception to action




AI
Machine Learning
Deep Learning
Deep Robot Learning
Robot Learning
Robotic AI
Robotics

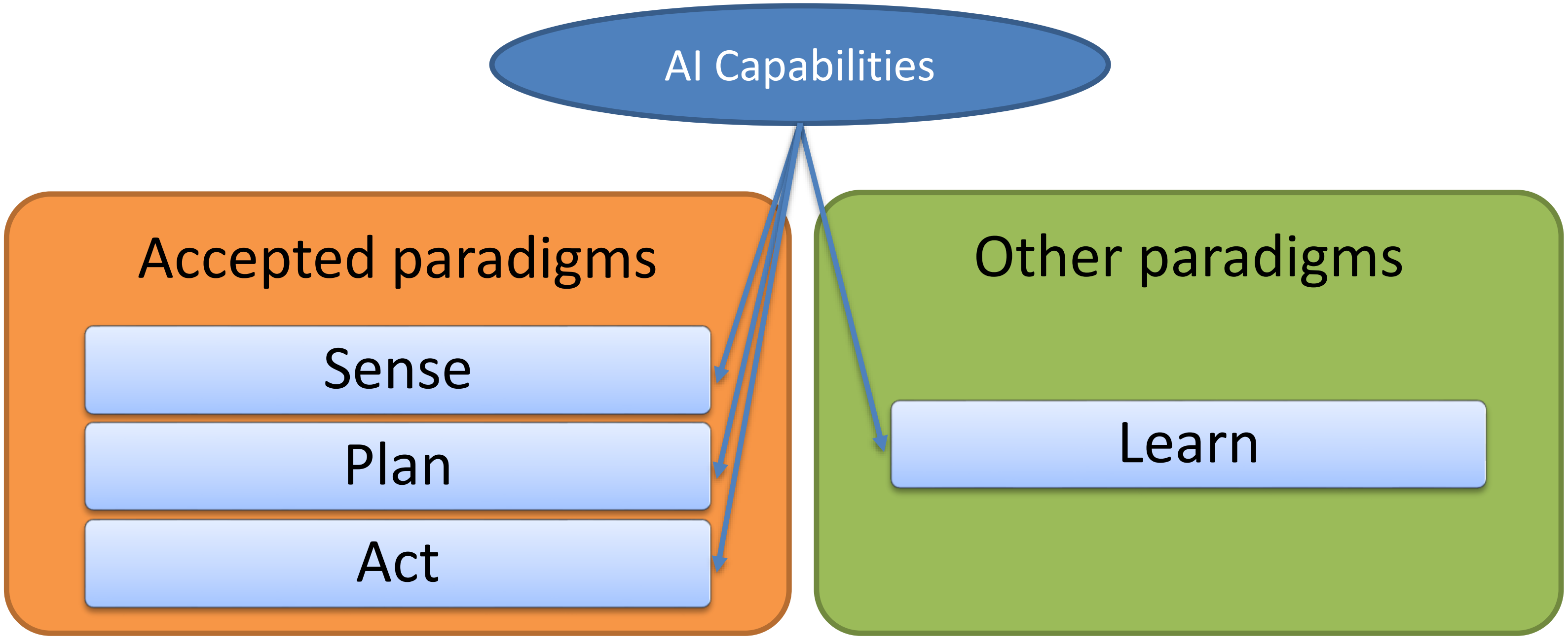
- How to Build Intelligent Agents
  - Intelligent behavior is conditioned by **knowledge**—we **make decisions** based on our **beliefs about the world**
  - How to represent intelligence in AI systems → Capabilities

Core capabilities
- Natural language processing (NLP)
- Knowledge representation (KR)
- Action plan/Reasoning
- Learning

Other capabilities
- Vision
- Robotics

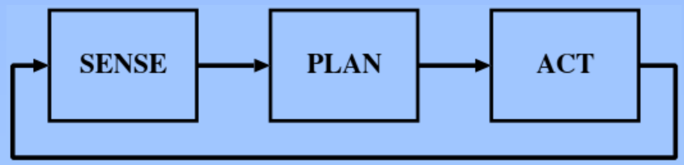
- How to Build Intelligent Robots
  - Understanding and modeling of the involved mechanics—Kinematics and dynamics
  - Designing actuator controllers—Closed-loop control
  - Task-specific motion and path planning
  - Sensor integration—Integration of various sensors
  - Noise and uncertainty modeling—Filtering and state estimation
  - Designing adaptive higher-level control policies—handling new situations

- How to Build Intelligent Robots
  - How to integrate intelligence in robots → Robot paradigm primitives + intelligent capabilities

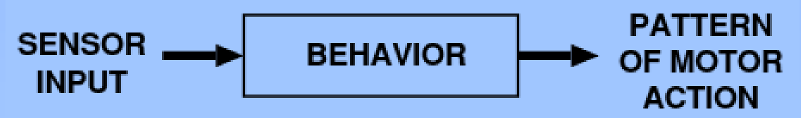


- How to Build Intelligent Robots
  - How to organize robot paradigm primitives → Robotic paradigms

- Hierarchical

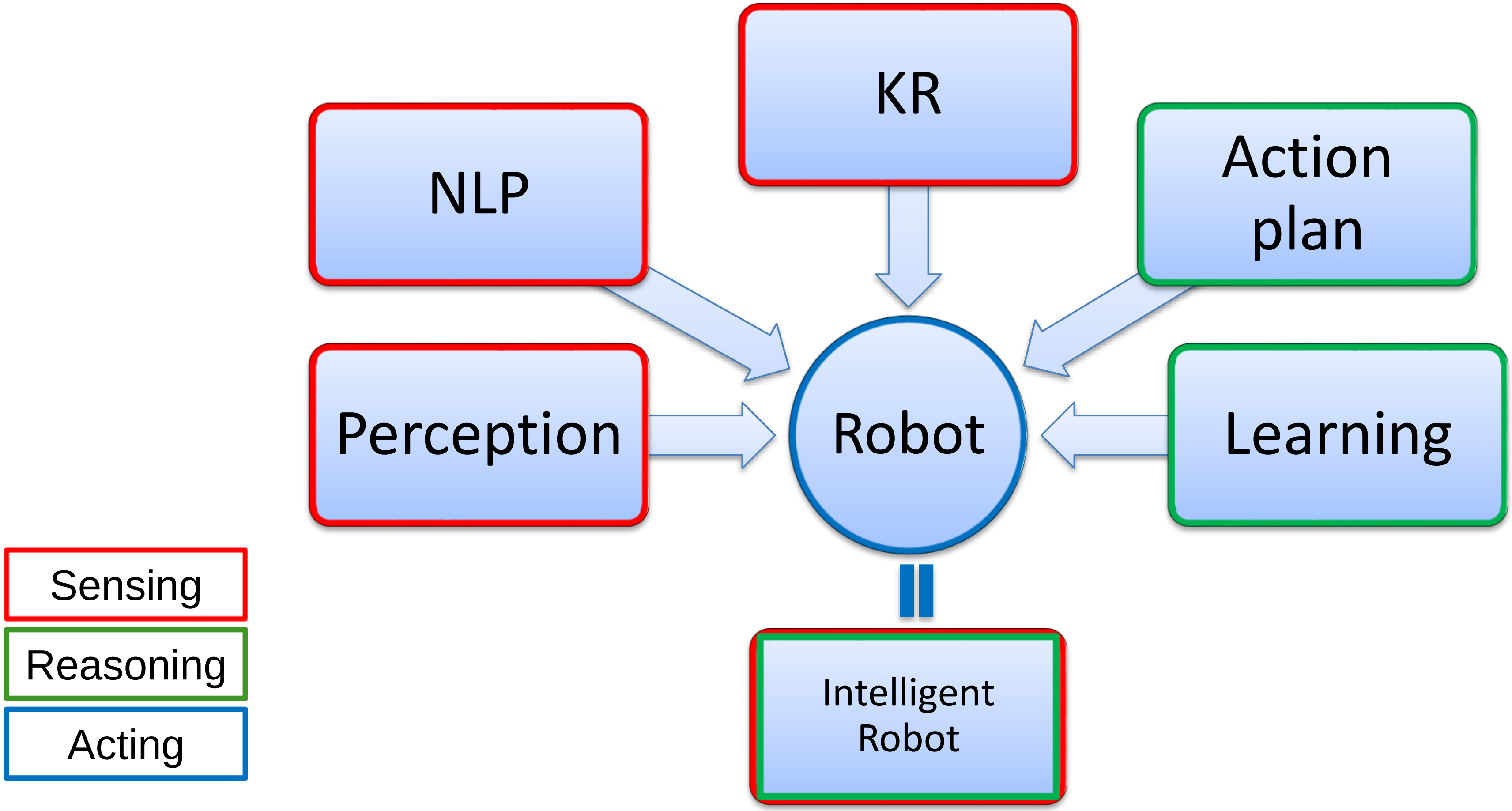


- Reactive / behavioral



- Hybrid (deliberative and reactive)

- How to Build Intelligent Robots



• Intelligent Robots — Perception

- Maps sensor measurements to internal representation of the world
- Classification of sensors
  - Proprioceptive sensors
    - measure values internally to the system (robot), e.g. motor speed
  - Exteroceptive sensors
    - information from the environment, like distances to objects, light
  - Passive sensors
    - energy coming for the environment
  - Active sensors
    - emit their proper energy and measure the reaction
    - better performance, but some influence on environment

• Intelligent Robots — Perception

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Tactile sensors (detection of physical contact or closeness; security switches)	Contact switches, bumpers	EC	P
	Optical barriers	EC	A
	Noncontact proximity sensors	EC	A
Wheel/motor sensors (wheel/motor speed and position)	Brush encoders	PC	P
	Potentiometers	PC	P
	Synchros, resolvers	PC	A
	Optical encoders	PC	A
	Magnetic encoders	PC	A
	Inductive encoders	PC	A
	Capacitive encoders	PC	A
Heading sensors (orientation of the robot in relation to a fixed reference frame)	Compass	EC	P
	Gyroscopes	PC	P
	Inclinometers	EC	A/P

A, active; P, passive; P/A, passive/active; PC, proprioceptive; EC, exteroceptive.

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• Intelligent Robots — Perception

General classification (typical use)	Sensor Sensor System	PC or EC	A or P
Ground-based beacons (localization in a fixed reference frame)	GPS Active optical or RF beacons Active ultrasonic beacons Reflective beacons	EC EC EC EC	A A A A
Active ranging (reflectivity, time-of-flight, and geometric triangulation)	Reflectivity sensors Ultrasonic sensor Laser rangefinder Optical triangulation (1D) Structured light (2D)	EC EC EC EC EC	A A A A A
Motion/speed sensors (speed relative to fixed or moving objects)	Doppler radar Doppler sound	EC EC	A A
Vision-based sensors (visual ranging, whole-image analysis, segmentation, object recognition)	CCD/CMOS camera(s) Visual ranging packages Object tracking packages	EC	P

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- Intelligent Robots — Perception
  - Vision: Rich in detail and readily available
    - Gives partial observations of the environment

Probabilistic approach: Sensor model , $\mathbf{P}(E|S)$

Object model
- Describe objects present in the visual world
- e.g. people, buildings, cars, trees

Rendering model
- Describes the physical, geometric and statistical processes that produce the stimulus from the environment

- Intelligent Robots — Perception
  - Vision: Rich in detail and readily available
    - The challenge is which aspects of the visual data to consider to achieve our goal
    - Solutions include actions based on:
      - **Feature extraction**
      - **Recognition**
      - Reconstruction

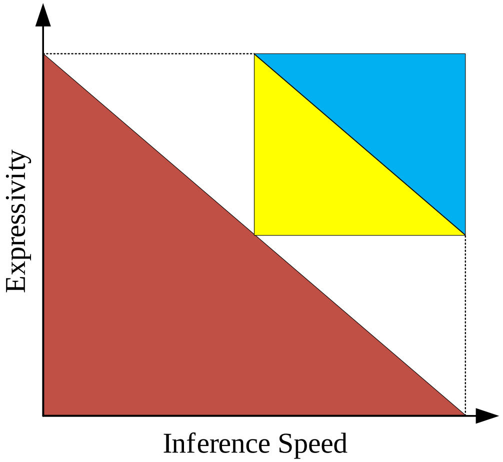
- # Intelligent Robots — NLP
  - Why natural language processing capability?
    - Communicate with humans (HMI)
    - Acquisition of information from written language
  - Information-seeking tasks
    - Text classification
    - Information retrieval
    - Information extraction
    - Text generation
  - Language model representation
    - As a set of rules called grammar
    - Probability distribution over sentences $\mathbf{P}(S = words)$

Probability distributions provide a logical way to handle ambiguity. E.g. "He saw her duck"

- Intelligent Robots — Knowledge Representation
  - Knowledge representation
    - Intelligent behavior is conditioned by knowledge
    - Knowledge is the relationship between an agent and a proposition
    - Reasoning builds our belief about the representation
  - Knowledge representation methodologies
    - Symbolic representation
    - Non-symbolic representation (**Connectionism**)

- Intelligent Robots — Knowledge Representation
  - Suitability metrics for KR formalisms
    - Epistemological adequacy → Knowledge quality
      - Complete and precise environmental representation
    - Computational adequacy → Algorithm complexity
      - Effective and efficient inference

Observation: *There is a tradeoff between these two adequacies, given that the very rich, expressive, and epistemologically appealing formalisms are typically accompanied by intractable inference problems*



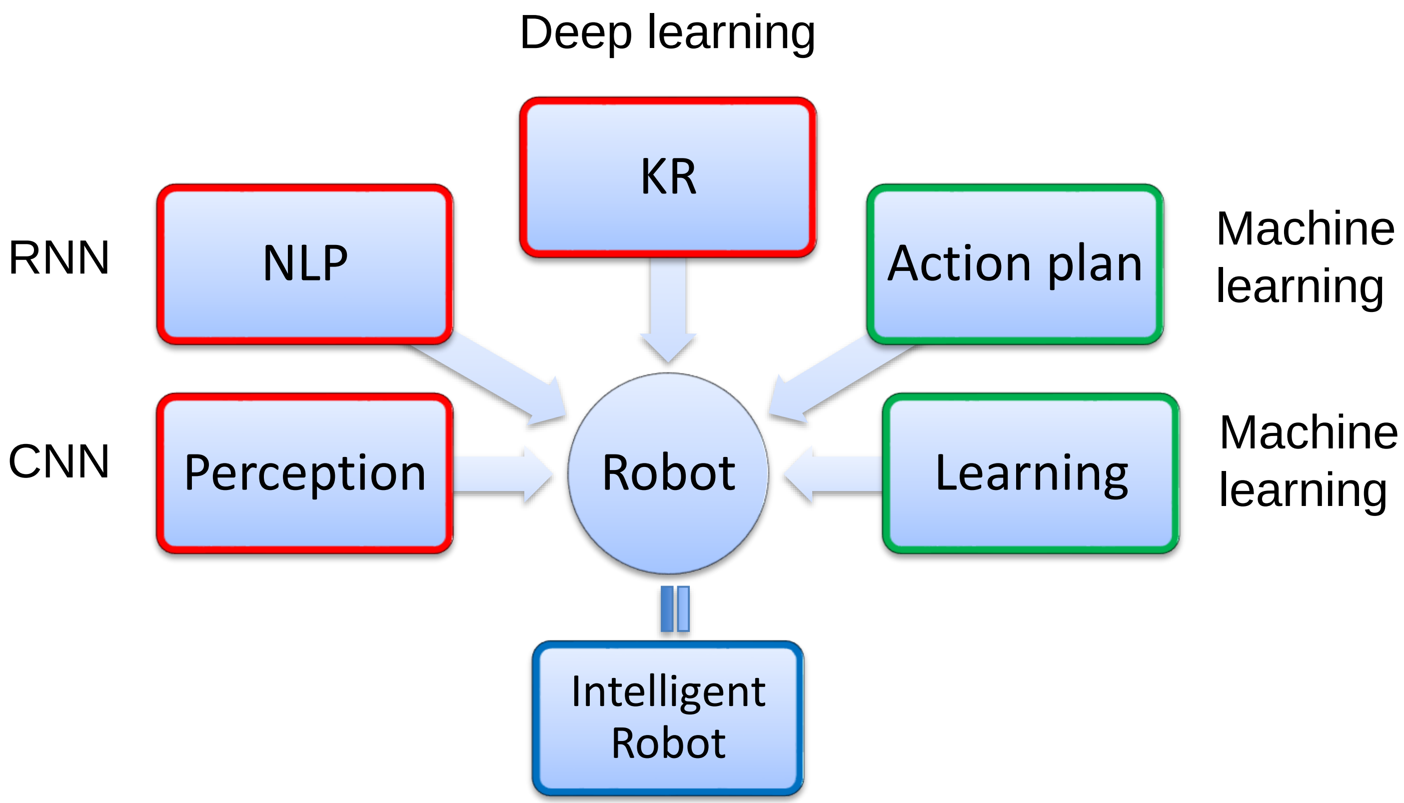
Intelligent Robots — Action Plan

- Planning manipulates the model of the world in order to decide what actions will bring about the desired effects
- Action planning includes **planning** and **scheduling**
- **Planning** is deliberating about a course of action for an agent to take to achieve a given set of goals
- **Scheduling** is allocating time and or resources to a set of actions such that given deadlines are met and resource constraints are respected
- Normally occur sequentially, plan first, then schedule

- Intelligent Robots — Learning
  - Learning is the ability to improve a system's own performance or knowledge based on its experience
  - Learning schemes of interest in robotics
    - Inductive logic learning
    - Statistical learning
      - Bayesian learning, kernel learning, and neural networks
    - Reinforcement learning

- Does machine learning need robotics?
  - Many search engines use techniques developed for robotics (software agents)
  - Robotics inspire methods for planning (used in operations research)
  - Simulation and animation industry (Reinforcement learning frameworks and Deep learning simulators
  - Kinematics provide additional sensing degrees of freedom (self-supervised learning and inference enhancement)

- Does robotics need machine learning?



- General Challenges
  - Uncertainty estimation
  - Closed-world vs Open-world assumption
  - Kinematics integration and active vision
  - Independent and identically distributed (iid) data
  - End-to-end evaluation. Solving a data set is not solving the problem

- General Challenges
  - The risk of the unknown
  - Transferability (static data vs dynamic world applications)
  - Extensive training of robots is slow
  - Minding the reality gap (simulation and reality)
  - Model sizes are still beyond most SoC computers can take

Questions?

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